

## High-Intensity Interval Training and Physiological Demands in Wheelchair Tennis Players: A Pilot Study

### Entrenamiento Interválico de Alta Intensidad y Demandas Fisiológicas en Tenistas en Silla de Ruedas: Un Estudio Pilot

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**Abstract.** Wheelchair Tennis is a dynamic sport that necessitates a blend of speed, agility, quickness, strength, power, and endurance. An athlete not only requires these attributes but also must maintain a high-performance level throughout an extended season. Consequently, adjustments in programming are essential to enhance cardiorespiratory capacity, upper-body strength, and agility proficiency in a manner that incorporates intermittent features. One viable approach is the utilization of high-intensity interval training (HIIT) methodology. Consequently, the aim of this research was to evaluate the alterations in cardiorespiratory fitness, musculoskeletal strength, and agility proficiency among wheelchair tennis athletes following a HIIT regimen. The study involved 30 wheelchair tennis players with spinal cord injuries aged between 19 and 28 years. They were divided into an experimental group, which participated in a HIIT program [EG, n = 15], and a control group, which adhered to a standard training regimen [CG, n = 15]. All participants underwent anthropometric assessments, the wheelchair yo-yo test, and hand grip evaluation. The results displayed a significant Time x Group interaction for the yo-yo test and hand grip evaluation, indicating a marked improvement in the intervention group ( $p < 0.001$ ). Conversely, no substantial changes were observed in the control group. Therefore, it could be claimed that the inclusion of a HIIT protocol in the daily training regime leads to a significant positive influence on the cardiorespiratory fitness, musculoskeletal strength, and agility capabilities of wheelchair tennis players.

**Key words:** physiology; exercise; sport; spinal cord injuries; cardiorespiratory fitness.

**Resumen.** El tenis en silla de ruedas es un deporte dinámico que requiere una mezcla de velocidad, agilidad, rapidez, fuerza, potencia y resistencia. Un atleta no solo requiere estos atributos, sino que también debe mantener un alto nivel de rendimiento durante una temporada prolongada. En consecuencia, los ajustes en la programación son esenciales para mejorar la capacidad cardiorrespiratoria, la fuerza de la parte superior del cuerpo y la competencia de agilidad de una manera que incorpore características intermitentes. Un enfoque viable es la utilización de la metodología de entrenamiento en intervalos de alta intensidad (HIIT). Por lo tanto, el objetivo de la investigación fue evaluar las alteraciones en la aptitud cardiorrespiratoria, la fuerza musculoesquelética y la competencia de agilidad entre los atletas de tenis en silla de ruedas que siguen un régimen HIIT. En el estudio participaron 30 tenistas en silla de ruedas con lesiones medulares de entre 19 y 28 años. Se dividieron en un grupo experimental, que participó en un programa HIIT [EG, n = 15], y un grupo de control, que se adhirió a un régimen de entrenamiento estándar [CG, n = 15]. Todos los participantes se sometieron a evaluaciones antropométricas, la prueba yo-yo en silla de ruedas y la evaluación de agarre manual. Los resultados mostraron una interacción significativa de Tiempo x Grupo para la prueba yo-yo y la evaluación de la prensión manual, lo que indica una marcada mejoría en el grupo de intervención ( $p < 0,001$ ). No se observaron cambios sustanciales en el grupo control. Como resultado, podría afirmarse que la inclusión de un protocolo HIIT en el régimen de entrenamiento diario conduce a una influencia positiva significativa en la aptitud cardiorrespiratoria, la fuerza musculoesquelética y las capacidades de agilidad de los tenistas en silla de ruedas.

**Palabras clave:** fisiología; ejercicio; deporte; lesiones medulares; aptitud cardiorrespiratoria.

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## Introduction

Engaging in adapted sports has been demonstrated as an effective strategy to enhance the well-being and overall quality of life for individuals with physical disabilities (“Cataldi et al., 2019; Côté-Leclerc et al., 2017; Farì et al., 2021; Yazicioglu, Yavuz, Goktepe, & Tan, 2012”). Consequently, consistent involvement in physical training programs contributes to enhancing the physical fitness of individuals with Spinal Cord Injuries (SCI) (“Kyriakides et al., 2019; Latino, Saraiello, Tafuri, 2023; Latino et al., 2023; Latino, Tafuri, 2023, 2024a-b; van der Scheer, Martin Ginis, Ditor, Goosey-Tolfrey, Hicks, West, & Wolfe, 2017; Vik, Lannem, Rak, & Stensrud, 2017”), albeit with more limited options for exercise modalities compared to those without disabilities. Insufficient physical activity may lead to a decline in health quality, characterized by muscle

weakness and reduced levels of cardiovascular, neurological, and endocrine functions (“Farì et al., 2023; Guerra et al., 2014; Mazzeo et al., 2016; Muscogiuri et al, 2016”). The cardiorespiratory system represents a crucial component of individual fitness, involving the lungs, heart, and the efficiency of blood vessels and capillaries in oxygen distribution throughout the body for energy production (“Aidar et al., 2022; Peters et al., 2021; Rocca et al., 2016; Silva et al., 2022”).

Adapted sports events are on the rise annually due to their numerous advantages and strong adherence to practice. A prime illustration of this trend can be observed in wheelchair tennis (WT). The association between WT and well-being has been firmly established (“Marks, 2006”). Participation in WT has the potential to enhance cardiovascular fitness, promote a favorable lipid profile, enhance bone health, and decrease the likelihood of cardiovascular

morbidity and mortality (“Pluim, Staal, Marks, Miller, & Miley, 2007”). WT serves as the modified version of traditional tennis (CT) and stands as one of the Paralympic sports engaged in by tennis competitors with impairments, particularly individuals with physical disabilities (“Sánchez-Pay, Torres-Luque, & Sanz-Rivas, 2016”).

Achieving proficiency in WT necessitates the acquisition of diverse tactical, technical, physical, and psychological competencies (“Rietveld, Vegter, der Woude, & de Groot, 2024”). With the evolution of the sport, physical attributes have gained increasing significance in determining success at the elite level. The physical requirements of WT are substantial. Undeniably, it is a fast-paced activity that demands a critical blend of speed, agility, quickness, strength, power, and endurance (“Yulianto, et al., 2024”).

The demands of international WT, along with the tournament format, lead to the contention that cardiorespiratory fitness plays a crucial role in achieving success at the global level. Moreover, prior studies indicate that WT players are able to cover a mean distance of  $2816 \pm 844$  m, maintaining an average heart rate ranging between 66-75% of their maximum heart rate during a match (“Williamson et al., 2024”). Demonstrating good physical attributes has been linked to elevating athletes' performance levels and facilitating prosperous sports careers (Sánchez-Pay et al., 2021). Consequently, enhancements in aerobic capacity have the potential to significantly boost athletic performance and overall quality of life for individuals with SCI, particularly in the context of sports and daily activities, by augmenting their physical capabilities (Ponzano, & Gollin, 2017). Indeed, some consider aerobic capacity as the quintessential metric for evaluating this aspect of physical fitness (“Sánchez-Pay, Torres-Luque, & Sanz-Rivas, 2016”).

Cardiorespiratory capacity ( $VO_{2max}$ ) represents a fundamental element of an individual's overall physical fitness, as it encompasses the functionality of the heart, lungs, as well as the capacity of blood vessels and capillaries to distribute oxygen throughout the body for the generation of energy. The equilibrium of various fitness constituents is imperative for sustaining bodily structure against gravitational and external forces, while also preserving the body's center of mass in relation to the pivot axis. Tailored physical training regimens aimed at enhancing cardiorespiratory fitness in persons with SCI are indispensable for their overall health. Additionally, attributes such as strength, velocity, force, and dexterity constitute other pivotal physical variables in the realm of WT (“Gollin, & Beratto, 2016”), facilitating rapid alterations in motion trajectory.

The aforementioned depiction underscores the importance of formulating a suitable aerobic endurance regimen in conjunction with upper-body strength and agility training for WT athletes. The movement patterns of wheelchair tennis players, encompassing forward, sideways, and backward motions amidst opponent attacks, significantly rely on cardiorespiratory capacity. Moreover, the nature of movement in wheelchair tennis is characterized by intervals, signifying rapid movements interspersed with pauses

(“Azeez, & Majeed, 2022”). Consequently, strategies aimed at enhancing cardiorespiratory capacity, upper-body strength, and agility should be tailored to accommodate these intermittent features. One viable approach is the utilization of high-intensity interval training (HIIT) techniques. HIIT represents a multifaceted exercise regimen characterized by high-intensity exertion coupled with brief recovery intervals (“Buchheit & Laursen, 2013”). This form of training is specifically designed to enhance cardiorespiratory fitness and strength among wheelchair tennis players.

Despite the presence of numerous articles on the topic of HIIT for enhancing physical fitness and the empirical evidence supporting its ability to enhance cardiorespiratory performance in WT, these aspects have not been given notable attention. Consistent with prior research, the development of training regimens customized for individuals with disabilities has not been adequately emphasized (“Dehghansai, Pinder, & Baker, 2021”). Research focusing on athletes with disabilities highlights the continued absence of tailored training programs that cater to the unique needs of each athlete within this population. It is imperative that exercise protocols are specifically designed to enhance the performance of these athletes (“Morsanuto et al., 2023”). Thus, the primary objective of this study is to address the existing research gap by introducing innovative HIIT-specific training programs aimed at enhancing the physiological responses of WT athletes. The anticipated outcome of this study is a substantial contribution to the development of training protocols for WT players in order to improve their cardiorespiratory performance.

## Method

### Study design

The investigation conducted a randomized controlled trial to assess the impact of a HIIT regimen on cardiovascular fitness, musculoskeletal strength, and agility in wheelchair tennis athletes. Participants were allocated to either the experimental or control group for a 16-week intervention. Following randomization, the researchers verified the similarity in baseline characteristics between the two groups and ensured double-blinding to conceal group assignments from both participants and evaluators. The experimental group underwent a resistance circuit training protocol, while the control group engaged in standard aerobic exercises targeting the upper body. Both cohorts adhered to their respective training programs for 16 weeks, attending sessions twice weekly, with assessments conducted before and after the training period.

### Participants

Interventions were performed a two-group pre-test-posttest design methodology. During the period between January and April 2024, 30 individuals afflicted with paraplegia resulting from spinal cord injury expressed their willingness to partake in the research. The criteria for inclusion were: (1) individuals engaged in wheelchair tennis for a minimum of two years, (2) expressed readiness to engage

in a 24-session training program, (3) did not report any pain, and (4) had engaged in a competitive event at least at the provincial level. Those excluded were individuals with cardiovascular ailments or neurological disorders. A total of 30 individuals, comprising 17 males and 13 females aged between 19 and 28 years, were discovered to meet the stipulated criteria.

The determination of the sample size was conducted utilizing G\*Power 3.1 (Heinrich-Heine-Universität Düsseldorf, Germany). A priori power analysis was executed, revealing that a sample size of 34 would yield adequate statistical power ( $\alpha=0.05$ ,  $1-\beta=0.80$ ) to detect a medium effect size ( $f=0.25$  or  $0.4$ ) given a correlation coefficient of  $p=0.80$  with 95% power and  $\alpha=0.05$ , utilizing a within-between mixed design. To mitigate potential experimental attrition caused by participant dropout, 36 subjects were initially enrolled. The athletes were recruited from the Italian Wheelchair Basket Federation. Before their involvement in the study, all participants provided written informed consent in compliance with the Helsinki Declaration and its subsequent revisions.

### Procedures

All measurements were carried out over two separate sessions. The testing sessions were separated by a 72-hour interval between the initiation of the program and the baseline assessment. During the initial session, participants completed a questionnaire revealing demographic details such as age, gender, medical history, smoking habits, and other characteristics. Following this, athletes participated in the yo-yo test to assess aerobic capacity both before and after the intervention. The students were subjected to individual evaluations and underwent each test in a consistent order, at the same time each day, and under similar experimental conditions. Both assessments and physical activity routines were outlined, supervised, and conducted by two skilled fitness trainers.

### Measures

The data was initially acquired through the initial assessment of various factors: (1) measurements related to human body dimensions, (2) levels of cardiovascular and respiratory endurance ( $VO_2\max$ ), and (3) strength of the upper-body muscles. The initial assessment was conducted to determine the athlete's strengths and areas needing improvement at the beginning of the study. Subsequent to a 12-week training program, a follow-up assessment of the aforementioned factors was carried out, as fitness assessments play a vital role in tracking and evaluating an athlete's capacity in terms of both aerobic endurance and strength. In order to gauge cardiovascular and respiratory endurance, a Field test was selected due to the advantages it offers compared to laboratory assessments, such as being more convenient, efficient, and cost-effective, making them particularly suitable for use throughout the competitive season.

### Anthropometric measures

A standardized protocol was utilized to conduct the anthropometric assessments ("Weiner, & Lourie, J.A., 1981"). Within a designated space, height and weight metrics were taken, ensuring the privacy of the participants. Individuals were requested to remove any personal items such as wallets, watches, or coats. Each measurement was carried out thrice, with validation consistently overseen by a proficient researcher to prevent inaccuracies. The participants' weight was determined utilizing a medical chair scale with a precision of 0.1 kg (Detecto 6868-C-AC-W - Bariatric Flip Seat Scale). For height measurement accuracy to the nearest 0.1 cm, a digital stadiometer was employed (Charder's HM200D, Charder Electronic Co., Taiwan) ("Okosun, Bhatt, Boltri, & Ndirangu, 2008"). Subsequently, the data collected from height and weight assessments were utilized in the computation of Body Mass Index (BMI) ( $\text{kg}/\text{m}^2$ ). BMI assessment was conducted both pre and post the implementation of intervention programs ("Rothman, 2008").

### Wheelchair Yo-Yo Test

The present iteration of the yo-yo test represents an adapted version ("Gürses, Akgül, Ceylan, & Baydil, 2018") of the original yo-yo test developed by Jens Bangsbo. Specifically tailored for individuals using wheelchairs, this version entails participants with disabilities performing the test within a distance shorter than the conventional 20 meters. While the standard yo-yo test typically spans a 20-meter course, wheelchair athletes may find this distance arduous, leading to quicker test completion and heightened emphasis on the anaerobic energy system. Hence, the concept of a modified yo-yo test was introduced by Yanci et al. (2015), wherein the distance covered in each shuttle was reduced to 10 meters (10 meters out and 10 meters back). Through their study, Yanci et al. (2015) determined the reliability of the 10-meter yo-yo test among wheelchair basketball players, establishing it as a suitable tool for assessing aerobic fitness in this population. Particularly beneficial for wheelchair sports emphasizing agility and turning capability, the 10-meter yo-yo test is deemed appropriate. To conduct the yo-yo 10-meter test, a diagram necessitates the placement of cones at 10-meter intervals, guiding the wheelchairs around turning points (Fig. 1).



Figure 1. Wheelchair Yo-Yo test.

### Handgrip strength test

The evaluation of handgrip strength, as described by Cronin, Lawton, Harris, Kilding, and McMaster (2017), involves assessing the maximal isometric strength of the hand and forearm muscles. This metric holds significance across various sports that require manual activities such as catch-

ing, throwing, or lifting. Specifically, the assessment is conducted on the dominant hand, ensuring the arm is fully extended along the vertical axis. During the evaluation process, participants are situated in their wheelchairs with strict adherence to maintaining arm extension without contact with the wheelchairs. The standardized testing procedure comprises three successive maximal isometric contractions lasting 5 seconds each, interspersed with a minimum rest interval of 60 seconds.

#### Training program

The execution of the HITT training regime occurs within the tennis arena, where athletes are assembled and provided with instructions regarding the conducted exercises. Prior to engaging in core exercises, wheelchair tennis players are instructed to engage in warm-up activities lasting 10-20 minutes. The subsequent activities included in the regimen are described as follows:

- **Y dynamic run:** The wheelchair tennis player moves through three cones placed behind the wheelchair, each loaded with a resistance band managed by the coach. The player commences running upon receiving a signal, and upon reaching the third cone, the coach releases the resistance band, allowing the player to continue towards the designated endpoint.
- **Reactive obstacle ball:** Positioned in front of the coach at a three-meter distance, the athlete is presented with a ball thrown by the coach. Placed amidst three obstacles, the athlete is directed to swiftly catch the ball, adjust movement towards the ball's direction, and navigate past the obstacles post-catching.
- **Zigzag run & ball reactive:** Involves a zigzag run spanning a meter, featuring six cones and ending with a lateral movement by the athlete. Following this, the athlete swiftly retrieves a tennis ball thrown by the coach towards an unspecified recipient and returns to the initial position, repeating the sequence thrice.
- **Obstacle Reactive agility shadow:** This task involves maneuvering through six obstacles using a racket while executing shadow movements at designated points. Athletes respond promptly to the coach's cues, running towards specified cones, mimicking basic tennis movements, and returning to the starting point.
- **T dynamic run and back:** Athletes begin at the starting line, propelling the wheelchair back and forth while awaiting instructions from the coach to advance through the aligned cones.
- **Side arm medicine ball throw:** The athlete initiates by throwing a medicine ball from the starting line, simulating forehand and backhand motions with a two-kilogram ball.
- **Reactive with ball:** Positioned at the starting line, the athlete navigates the wheelchair laterally as the feeder prepares to direct the ball in various trajectories, which the athlete catches.
- **Shake left and right on the chair:** Involves lateral

movements of the wheelchair to the left and right.

- **Hexagon obstacle:** In this exercise, athletes navigate through a hexagon structure, moving towards its center and then reversing out of it.
- **Run and back forth:** Athletes engage in a sequence of forward and backward movements with the wheelchair, pedaling forward and backward three times consecutively.

#### Statistical analysis

Statistical analysis was carried out utilizing SPSS software (version 21.0; IBM Corp., Armonk, NY, USA), with computation of means and standard deviations for all variables. Normality assumptions were validated through the Shapiro-Wilk test, while Levene test was utilized to evaluate homogeneity of variances. Group disparities at baseline were assessed employing an independent sample t-test. Evaluation across time for all outcome measures was conducted via a one-way ANOVA for repeated measures, and within-group variances were scrutinized using paired-sample t-tests (pre- and post-intervention). The extent of the significant 'Time x Group' interaction was scrutinized utilizing the partial eta squared ( $\eta^2_p$ ) value, with delineations of small ( $\eta^2_p < 0.06$ ), medium ( $0.06 \leq \eta^2_p < 0.14$ ), and large ( $\eta^2_p \geq 0.14$ ). Furthermore, Cohen's d was utilized to ascertain effect sizes for pairwise comparisons, with categorizations of small ( $0.20 \leq d < 0.50$ ), moderate ( $0.50 \leq d < 0.79$ ), and large ( $d \geq 0.80$ ). Statistical significance was deemed as  $p < 0.05$ . A P-value less than 0.05 was considered the threshold for statistical significance in all instances.

#### Results

All subjects received the designated treatment conditions as allocated, and no instances of injuries were documented during the entirety of the experiment. The individuals involved in the study displayed a consistent lack of discrepancies in terms of age, gender, or anthropometric characteristics. ( $p > 0.05$ ) (Table 1). The results of the data pertaining to all variables of interest are presented in Table 2.

Table 1.  
Characteristic of participants.

Variable	EG (n = 15) Mean $\pm$ SD	CG (n = 15) Mean $\pm$ SD
Age (y)	22.66 $\pm$ 3.17	27.06 $\pm$ .45
Height (cm)	165.60 $\pm$ 2.09	166.66 $\pm$ 4.27
Weight (kg)	60.13 $\pm$ 1.40	59.40 $\pm$ 1.45
Body mass index ( $\text{kg}\cdot\text{m}^{-2}$ )	22.60 $\pm$ 0.26	21.65 $\pm$ 1.05
Sex, n (%)		
Male	8 (26.67)	9 (30.00)
Female	7 (23.33)	6 (20.00)

Note: y= years; cm= centimeters; kg= kilograms; n (%)= percentage.

Table 2.  
Changes in cardiorespiratory fitness, musculoskeletal strength, and BMI after a 12-week circuit training program.

	Experimental Group (n = 15)			Control Group (n = 15)		
	Baseline	Post-test	Δ	Baseline	Post-test	Δ
Wheelchair	1016.13	1022.26	6.13	1016.53	1013.33	-3.20
Yo-Yo Test	(1.25)	(2.25)†*	(1.12)	(1.50)	(4.15)	(4.49)
Hand Grip test	49.06	57.06	8.00	48.66	47.86	-0.80
	(1.03)	(1.94)†*	(0.92)	(1.11)	(2.06)	(1.74)

Note: values are presented as mean ( $\pm$  SD); Δ: pre- to post-training changes; †Significant 'Group x Time' interaction: significant effect of the intervention ( $p < 0.001$ ). \*Significantly different from pre-test ( $p < 0.001$ ).

#### Wheelchair Yo-Yo Test

A two-factor repeated measures ANOVA found a significant 'Time x Group' interaction for the 12 minutes wheelchair propulsion distance test ( $F_{1,28} = 71.57$ ,  $p < 0.001$ ,  $\eta_p^2 = 0.71$ , large effect size). The post-hoc analysis revealed a significant improvement in the score for this variable ( $t = 21.10$ ,  $p < 0.001$ ,  $d = 5.45$ , large effect size) in the intervention group. No significant changes were found for the control group ( $p > 0.05$ ).

#### Hand grip test

A two-factor repeated measures ANOVA found a significant 'Time x Group' interaction for the Hand grip test ( $F_{1,28} = 298.94$ ,  $p < 0.001$ ,  $\eta_p^2 = 0.91$ , large effect size). The post-hoc analysis revealed a significant improvement in the score for this variable ( $t = 33.46$ ,  $p < 0.001$ ,  $d = 8.63$ , large effect size) in the intervention group. No significant changes were found for the control group ( $p > 0.05$ ).

## Discussion

The objective of the current research was to investigate the impact of a 16-week HIIT intervention program on the cardiorespiratory fitness, musculoskeletal strength, and agility skills of wheelchair tennis players with paraplegia resulting from Spinal Cord Injury.

Within this investigation, HIIT regimen was opted as the mode of exercise for designing training protocols aimed at enhancing the cardiovascular fitness and musculoskeletal strength of wheelchair tennis athletes. The conclusions drawn from this study propose that the integration of a HIIT program into the regular training regime of tennis players can lead to a substantial enhancement in physiological performance.

The HIIT-specific training protocols encompass models that prompt rapid movements, reactions, and changes in direction. Hence, the incorporation of HIIT techniques, involving actions, reactions, and directional changes, can enhance the cardiovascular fitness, reactive agility, and musculoskeletal strength of wheelchair tennis players ("La Torre et al., 2023; Latino et al., 2021"). While several research works have scrutinized the effectiveness of HIIT training in enhancing physical fitness, HIIT training is predominantly renowned for its impact on endurance and speed in running activities ("Ponzano, & Gollin, 2017; Sindall, 2016"). Furthermore, within the realm of WT,

there remains a scarcity of studies. Consequently, the introduction of HIIT-specific training programs represents a significant advancement in augmenting the reactive agility of WT athletes ("Yulianto, & Yudhistira, 2021").

WT is a sport that necessitates a high level of physical demand, along with a considerable amount of skill and technical proficiency. The elements of acceleration, speed, and agility hold particular significance due to the fast-paced nature of the game, where adept chair and ball handling skills are crucial. Upholding a superior level of fitness is essential to sustain the intensity of effort. For wheelchair athletes, the strength of upper-extremity muscles plays a vital role ("Paulson, & Goosey-Tolfrey, 2017"). These muscles in WT are utilized for both manipulating the racket and propelling the wheelchair. Enhancing strength could potentially enhance athletes' performance in competitions; nevertheless, it remains uncertain whether improved speed and agility would positively impact gameplay under competitive conditions. Engaging in strength training within WT may have prompted specific neural adjustments, such as heightened motor unit activation rates. These neural adaptations, including heightened motor unit synchronization and firing rates, likely contributed to advancements in speed.

The development of strength was likely a consequence of neural adaptations due to the brevity of the training period. The significance of these adaptations is widely acknowledged in the initial stages of strength training. Research by Iglesias et al. (2019) has indicated the critical role of upper extremity strength in individuals using wheelchairs. In a study by Janssen et al. (2022), a robust positive correlation was established between upper-body isometric strength and sprint power. Soyulu, Yıldırım, Akalan, Akinoğlu, & Kocahan (2021) found that the commencement of wheelchair movement hinges on upper-extremity strength. Heyward, Vegter, De Groot, & Van Der Woude (2017) observed a connection between sprint performance, disability level, and wheelchair propulsion technique. Dehghansai, Lemez, Wattie, & Baker (2017) conducted high-intensity training for 8 wheelchair athletes with SCI and 8 healthy physical education students.

Agility in conventional tennis pertains to a rapid alteration in the positioning of the foot, transitioning swiftly from one stance to another. Conversely, in WT, agility is centered around optimizing the functionality of the upper extremities to propel the wheelchair with speed and efficiency. Consequently, the training regimen for normal tennis must be distinct from that of WT. Moreover, tennis is characterized by rapid movements interspersed with moments of rest, necessitating a training approach tailored to these specific attributes ("Rietveld et al., 2019"). This scenario mirrors the demands of WT, where despite the focus being on the upper extremities, rapid movement remains essential. The intricate role played by the upper extremities involves maneuvering the wheelchair and executing various techniques. This underscores the importance of possessing substantial upper-body strength and robust cardiorespiratory fitness. Hence, the recommended training method

aligned with the motion characteristics and energy systems is HIIT.

HIIT is reputed for enhancing physical fitness, particularly in sports involving non-cyclical movements such as striking, kicking, throwing, leaping, and bounding (“Alim, Rismayanthi, Yulianto, & Miftachurochmah, 2023”). The training approach of HIIT in conjunction with specific training protocols presents a highly appropriate amalgamation for enhancing the aforementioned attributes in WT athletes. Consistent with existing literature, the utilization of HIIT methodology incorporating plyometric exercises has been shown to enhance endurance, speed, and agility (“Gavel, Macrae, Goosey-Tolfrey, & Logan-Sprenger, 2023”). Research conducted by Kabdwal et al. (2023) demonstrated that the integration of high-intensity training with explosive drills significantly improved agility in young soccer players. This finding is corroborated by another study indicating that the incorporation of HIIT routines with targeted drill methodologies produced a notable enhancement in agility among young tennis players (“Claus et al., 2016; Messina et al., 2015”).

In general, HIIT is a form of physical exercise characterized by rapid movements interspersed with periodic breaks tailored to the specific requirements of various sports disciplines. The incorporation of technical drills, bodyweight exercises, and resistance training into HIIT regimens has been advocated (“Yudhistira et al., 2021”). HIIT relies on the glycolytic and oxidative energy systems for fuel during workouts. Furthermore, due to its high-intensity nature, HIIT sessions are typically brief, lasting between 10 to 30 minutes. It is crucial to carefully calibrate the exercise volume to prevent instances of overtraining. The implementation of HIIT protocols has been shown to enhance both aerobic and anaerobic physical performance and functional capacity (“Buchheit & Laursen, 2013”). The design of HIIT training programs has been observed to significantly enhance the reactive agility skills of WT players.

The current investigation offers evidence supporting a positive relationship between HIIT training and cardiorespiratory fitness, musculoskeletal strength, and agility performance in WT athletes. However, there are limitations to be considered. It is important to note that WT involves multiple physical components, such as endurance, speed, and power, among others, which were not fully captured in the data analysis. Furthermore, the clinical significance of these findings would be strengthened by studies involving larger sample sizes. Another drawback is the inadequate duration and number of sessions, which hindered the assessment of long-term effects. Additionally, the evaluation of cardiopulmonary endurance was solely based on the 12-minute propulsion distance, without measuring the  $VO_{2peak}$  value. Future research should aim to also examine oxygen consumption. It is recommended that upcoming studies explore the combination of diet plans and exercise regimens to facilitate weight loss. Addressing these issues is crucial for the development of standardized exercise protocols and home training regimens for individuals within the community who have paraplegia

due to spinal cord injuries. Hence, forthcoming research endeavors should investigate analogous variables within a more extensive and diverse sample. Notwithstanding these constraints, the results acquired may offer valuable perspectives for forthcoming research endeavors. Accordingly, the effectiveness of the study was augmented by a systematic approach that produced immediately applicable positive results for daily training regimens. The findings of this study could provide a meaningful contribution to the domain of programming, specifically tailored for wheelchair tennis coaches and practitioners, serving as the foundation for evidence-based workout routines. Furthermore, the researchers also aspire that subsequent researchers can address the limitations of this study.

## Conclusion

Based on the findings and subsequent discourse, it can be inferred that the targeted design of HIIT has a favorable content validity in enhancing the cardiorespiratory fitness, musculoskeletal strength, and agility prowess of WT athletes. These findings emphasize the critical importance of meticulously selecting HIIT protocols to optimize physiological results. The study demonstrates that the integration of a HIIT regimen stands as a feasible strategy for WT athletes, augmenting their overall physical health and engagement. These results present practical implications for both the general population and elite sportsmen, underscoring the necessity of flexibility in tailoring exercise routines to individual preferences, time constraints, or specific training objectives. Consequently, incorporating an exercise program that features HIIT techniques emerges as the most advantageous method for elevating physiological performance among WT athletes.

## Author Contributions

Conceptualization, F.L. and F.T.; methodology, F.L. and F.T.; software, R.M.R.; validation, F.L.; formal analysis, F.L.; investigation, F.L.; resources, F.T.; data curation, F.L. and F.T.; Bibliographical research, S.H., S.N. and A.K.; writing—original draft preparation, F.L.; writing—review and editing, F.L.; supervision, F.L. and F.T.; project administration, F.T.; funding acquisition, E.S. All authors have read and agreed to the published version of the manuscript.

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## Conflicts of Interest

The authors declare no conflicts of interest.

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